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FATIGUE OF PLAIN AND FILLET-WELDED "T-1" STEEL

Progress Report No. 1

by

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A B S T R A C T

This report presents a fatigue testing program that simulates the flange-to-web fillet-welded region of a cyclically loaded beam by axially loaded specimens.

Tests completed to date are reported and discussed. It was found that descaling by shot blasting lowered the fatigue resistance of plain specimens. The comparison of two groups of specimens welded with electrodes of different strengths proved inconclusive.

A description of specimens and test procedures required to complete the present program conclude the report.

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I INTRODUCTION

Since the introduction of the constructional quenched and tempered alloy steel, 'T-1', studies have been made on the fatigue resistance of plain specimens with various surface conditions, specimens butt-welded by various processes and plate specimens cyclically loaded in the plastic range.[1] Prior to the initiation of the project herein reported, however, no investigations had been made concerning the effects of fillet welds on the fatigue behaviour of 'T-1' steel.

The test program that is the subject of this progress report was designed to study the fatigue resistance of non-load-carrying longitudinal fillet welds such as the flange-to-web fillet weld in the pure moment region of a welded built-up girder. Instead of testing only built-up beams under cyclic loading, it was decided to test small axially loaded welded specimens which simulated the critical region of the beam, Fig. 1. Similitude would then be verified by testing beams of similar geometric proportions, Fig. 2.

The actual testing was preceeded by a review of the existing literature treating fatigue tests of both mild and alloy structural steels including 'T-1' steel. A report[1] reviewing these tests plus an introduction to the phenomenon of structural fatigue was published by Fritz Engineering Laboratory in November, 1961.

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1. Superscripts refer to references in the Bibliography

II. TEST PROGRAM

Fatigue behaviour of a structural member is completely defined only when the load spectrum to which a member is subjected, the nature and condition of the member and the environment in which it will function are defined. The factors influencing the fatigue resistance of a structural member or laboratory specimen may be categorized as follows:

A. Load Spectrum

1. Maximum stress
2. Stress ratio, R ($R = S_{min.}/S_{max.}$)
3. State of stress
4. Repetition of stress
   a. Regular or random
   b. Frequency
   c. Rest periods
5. Understressing or overstressing

B. Nature and Condition

1. Prior stress history
   a. Presence or absence of residual stresses
   b. Work hardening
2. Size, shape, and surface condition of specimen
   a. Presence of notches
   b. Size effects (simulation of a member or part by a small specimen)

3. Metallurgical Structure
    a. Microstructure, grain size, and chemical properties.
4. Welding
    a. Mechanical effects
    b. Metallurgical effects

C. Environment
1. Temperature
2. Atmosphere

The present test program treats only the stress ratio, maximum stress, surface condition and type of weld metal as variables. A parallel pilot study treating the effects of stress gradient on fatigue resistance has also been conducted and is reported elsewhere.[2]

The test program consists basically of the following series of specimens:

1. Twelve plain axially loaded specimens with "as received" surfaces tested at each of three stress ratios, R = 1/4, R = 0, and R = -1.
2. Twelve additional plain, descaled, specimens at R = 0 tested to establish a preferred surface condition for the plain specimens. (4 descaled specimens were also tested at R = 1/2).
3. Twelve longitudinal fillet welded tee specimens (axially loaded) tested at each of three stress ratios, 1/2, 0, and -1.

4. Twelve additional tee specimens fabricated with a higher strength electrode than those above at R = 1/2, to compare two different welding electrodes.

5. Six small welded built-up beams at R = 1/4 and twelve small beams at R = 1/2 to verify similitude with the tee specimens.

6. Four large welded, built-up beams to "spot check" predictions based on the tee specimens.

The program as outlined above is summarized in the following table, and the tests completed to date are indicated.

SPECIMEN DESCRIPTION	STRESS RATIO			
	R = 1/2 (H)	R = 1/4 (Q)	R = 0 (Z)	R = -1 (R)
Plain, As Received (PU)		12*	12*	12*
Plain, Descaled (P)	4*		12*	
Fillet-Welded Tee (W) (low str. electrode)	12*		12	12
Fillet-Welded Tee (W) (high str. electrode)	12*			
Small Beams (a)	6	6		
Small Beams (b)	6			
Large Beams	2	2		

* Tests completed to date.

Each specimen was given a mark such as PU-5-Z. The designation is described below:

FIRST LETTER		DIGIT	LAST LETTER	
P	: Plain, descaled	Number of the	H	: R = 1/2
PU	: Plain, as received	specimen	Z	: R = 0
W	: Fillet-welded	in the series	R	: R = -1
			Q	: R = 1/4

All specimens except the large beams will be tested in a 220 kip Amsler Alternating Stress Machine at a frequency of 500 cycles per minute. The large beams will be tested on a test bed using an Amsler 220 kip Pulsator and Jacks.

Initially, test results will be presented in the form of the usual S-N curves but, upon completion of the present test program, the AWS-WRC Diagram (sometimes called the modified Goodman Diagram) will be utilized to present the data in a form more useful to designers.

III. THE SPECIMENS

1. GENERAL

All specimens in this test program are fabricated from flange quality "T-1" steel. The chemical composition, mechanical properties and metallurgical treatment are summarized in Table 1.

2. PLAIN SPECIMENS

The plain specimens, Fig. 3, are fabricated from 3/4 inch plate. The width of the specimens is reduced from 3 inches in the grip region to 1-7/8 inches in the test section by transition radii of 6 inches. A radius of 9 inches would result in a smooth stress flow, with no stress concentration at the transition, however, the fabricating agency is able to produce a maximum radius of only 6 inches. The machined edges of all plain specimens are polished to a No. 8 finish.

The surfaces of all plain specimens are in an "as received" condition except the series P-1-H to P-4-H and P-1-Z to P-12-Z inclusive. The surfaces of the latter series were descaled by a Pangborn Roto Blaster with a vane angle of 78 degrees using round steel shot, SAE 170, and an exposure of 10 minutes per surface.

3. WELDED TEE SPECIMENS

The welded tee specimens, Fig. 4, are fabricated by welding a 3/8 inch x 2-3/32 inch web plate to a 3/4 inch flange of the same shape as a plain specimen. Manual tack welds, 3/16 inch x 4 inches, are placed at the center of the specimens and then longitudinal 1/4 inch fillet welds covering the tack welds are run for the full length of the specimen by an automatic submerged arc process. The 3/16 inch tack weld simulates a procedure used to facilitate fabrication of a flange-to-web connection in practice. Specimens W-1-H to W-12-H were fabricated with a "low strength" electrode and W-20-H to W-31-H inclusive were fabricated with a "high strength" electrode. The welding conditions are listed in Table 2. All welded specimens are descaled in the same manner as the plain specimens mentioned above.

The unique manner in which the tee specimens are gripped in the testing machine requires end blocks attached by high strength bolts to the ends of the web, see Fig. 5. This method of gripping permits the end of the longitudinal fillet weld to be located outside of the stressed portion of the specimen thus removing a source of failure initiation that has plagued most fatigue studies of fillet welds.

4. SMALL BEAM SPECIMENS

The small beam specimens, Fig. 6, consist of two 3/4 inch flanges and a 3/8 inch web. The 1/4 inch automatic submerged flange-to-web fillet welds are run over 3/16 x 4 inch manual tack welds at the center of the beam. It will be noticed that the flange-to-web region of the small beam is identical to the cross section of the tee specimen.

A "pilot" small beam was fabricated at Fritz Engineering Laboratory using AIRCO 312 (E7016) electrodes laid manually.

5. LARGE BEAM SPECIMENS

The large beam specimens, Fig. 7, will consist of two 3/4 x 4 inch flanges and a 3/8 x 8 inch web. The welding procedure will be the same as that used in the fabrication of the small beams.

IV COMPLETED TEST RESULTS

1. PLAIN SPECIMENS

Initially, four descaled plain specimens were loaded cyclically at R = 1/2. P-1-H, P-2-H and P-3-H were stressed for several million cycles without failure. Their maximum stresses were increased and they were stresses cyclically in these new ranges until failure occurred. Table 3 and Fig. 9 present the results of these tests.

Twenty-four plain specimens were tested at the stress ratio, R = 0. Twelve were in the "as received" condition and twelve were descaled. The results are listed in Tables 4 and 5 and graphically compared in Fig. 8. The S-N Curves in Fig. 8 were fit to the data by the "least squares" method. Specimens PU-8-Z, PU-9-Z and PU-10-Z were excluded from the calculations.

It was then decided that the remaining plain specimens would be tested in the "as received" condition. The results of the tests with a stress ratio R = -1 are presented in Table 6 and Fig. 9. The test results for R = 1/4 are shown in Table 7 and Fig. 9. These S-N Curves were also fit to the experimental data by the "least squares" method.

In Tables 3 to 7 inclusive, the dimension "x" is the distance from the center-line of the specimen to the fracture measured parallel to the longitudinal axis.

Fig. 10 presents the fatigue resistance of plain, "as received" specimens in the form of an AWS-WRC Diagram.

2. WELDED TEE SPECIMENS

In order to select a welding electrode for the balance of the welded specimens, two different electrodes were compared at R = 1/2 by means of 24 tee specimens. Twelve were fabricated with a "low strength" electrode (Lincoln L-70) and twelve with a "high strength" electrode (Page 8620). The data for these tests are presented in Tables 8 and 9 and Fig. 11. Specimens W-11-H and W-12-H survived lives of several million cycles at a relatively low stress and were subsequently tested at a stress high enough to cause failure in less than a million cycles.

In Tables 8 and 9, "x" is the distance from the center-line of the specimen to the fracture. The S-N Curves in Fig. 11 were also fit to the experimental data by the "least squares" method.

3. "PILOT" SMALL BEAM

A small beam similar to that in Fig. 6 was tested to check the machine "setup". Loads were applied symmetrically about the mid-span, 8 inches apart, and the stress in the weld varied from 40 to 80 ksi (R = 1/2). Failure occurred at the midspan in the weld after 315.6 kilocycles. This result is plotted in Fig. 11.

V DISCUSSION OF TEST RESULTS

1. PLAIN SPECIMENS

A. Effect of Descaling

It can be seen in Fig. 8, that descaling by shot-blasting reduced the fatigue strengths of plain specimens by about 10%. In the descaling operation by sand or shot-blasting, the notching of the surface reduces the fatigue strength while the work-hardening caused by compression of the surface increases the fatigue strength. The former is predominate in sand and shot-blasting while the latter is predominate when steel shot peening is employed. The main difference between shot-blasting and shot peening is the removal, in the case of shot peening, of fragmented shot which produces the notching action. The particles are not removed in shot-blasting.

Of interest in the above matter are tests cited by Cazaud[3]. Fatigue tests were made on sand blasted rotating bending specimens of a 0.54% carbon steel (Y. S. = 77 ksi, U. T. S. = 115 ksi, fatigue limit = 47.5 ksi) in which the jet pressure, angle of incidence and size and shape of particles were varied. When the jet was normal to the specimens, round particles reduced the fatigue limit to 42 ksi, and fragmented sand particles reduced it to 43.5 ksi. This is an 8.5% to 11.5% reduction. In the case of fragmented sand, the jet angle was decreased to 70° and the fatigue limit fell to 37.2 ksi. On the other hand, Cazaud noted that descaling by shot peening could raise the fatigue limit to 55.2 ksi in complete reversal.

In a literature survey studying the advantages of shot peening cyclically loaded steel parts, Horger[4] summarized that, in general, fatigue strength was increased by shot peening although this effect diminished with an increase in shot size. Opposed to this, Lessells and Murray[5] recorded that the fatigue limits of quenched and tempered SAE 9260 steels were lowered by shot peening. They believed that this was caused by unfavorable stresses remaining from heat treatment. Frye and Kehl[6] found that the fatigue strength of a 0.54% carbon steel (Y. S. = 76.7 ksi, U. T. S. = 115.7 ksi) was slightly lowered by blasting with very fine particles, a mixture of No. 90 shot and No. 60 steel grit. They also noticed a slight decrease in surface hardness. Horger, Grover, and Jackson[7] called attention to the existence of an optimum intensity of peening above which the fatigue strength decreased instead of increasing. In the case of SAE 4340 steel, they showed that, for intensities much greater than optimum, the fatigue strength fell below that of the untreated steel.

Although the descaled specimens in the current tests were exposed for 10 minutes per surface during the descaling operation, the fine particles of shot did not have a significant peening effect. Table 10 shows that an "as received" specimen, PU-3-R, had an average surface hardness of 22 Rockwell C while a descaled specimen, P-8-Z, had an average Rockwell C hardness of 25. The reduction in fatigue strength is probably due to the notching effect of the shot fragments rather than a less ductile surface metal due to work-hardening.

B. <u>Fracture Initiation</u>

A reference to Tables 3 to 7 inclusive will show that, for the most part, failures of the "as received" specimens were initiated at or near the point of tangency where the transition from test section to grip section begins. At this point, the stress concentration factor is approximately 1.1 and, therefore, the maximum stress (the stress at which the fracture starts) exceeds the nominal stress, P/A, by about 10%. This would lower the fatigue life since the actual stress is higher than the stress plotted on the ordinate of the S-N Curve. This is offset, however, by the fact that the stress gradient existing at the transition will tend to raise the fatigue strength for a given nominal stress. The studies performed by Heins[2] indicate that the existence of a stress gradient can increase the fatigue life considerably above the fatigue life for the same maximum stress with a stress gradient of zero. It is therefore felt that the nominal maximum stress versus fatigue life is valid as an expression of the S-N Curve for the plain specimens.

C. Effect of Understressing

The fatigue lives of some steels may be raised by understressing, stressed at or below the fatigue limit for a great number of cycles. On the other hand, it appears that high strength, heat treated steels benefit very little from understressing.[1] To check this hypothesis, it was decided to increase the maximum stress of "run-out" specimens and load cyclically to failure.

In Fig. 9, it will be seen that P-1-H and P-2-H were tested at two different maximum stresses. They bracketed P-4-H which was tested at only the higher maximum stress. It should be noted that P-1-H was yielded statically for reasons stated below before it was tested at the higher stress.

PU-4-R, PU-12-R, PU-8-Z, PU-10-Z, and PU-3-Q were also considered "run-outs" and were subsequently tested at higher cyclic stresses until failure.

It appears that the above mentioned plain specimens did not demonstrate any increase in fatigue resistance due to understressing and it is suggested that "run-out" specimens of "T-1" steel be considered as previously untested specimens when cyclically loaded to failure at a higher stress.

D. Effect of Camber and Verification of the Stress Concentration Factor

P-1-H and PU-10-Z were instrumented with SR-4 electric strain gages and tested statically for two reasons:

1. To study the effect of camber out of the plane of the specimen.
2. To verify the computed stress concentration factor at the transition.

P-1-H, with a maximum camber out of its plane equal to 1/8 inch, was tested statically after 2,283 kc at $S_{max.}$ = 77 ksi. Fig. 12a indicates the stress distribution at the transition before and after static yielding. Fig. 12b indicates the stress distribution at the center of the test section before and after yielding. It will be seen that biaxial bending was present before yielding but, after yielding, the specimen behaved as one in uniaxial tension.

PU-10-Z was tested cyclically at $S_{max.}$ = 50 ksi and was tested statically at lives of 0 kc, 2020 kc and 4294 kc. This specimen was cambered 1/32 inch out of its plane and, therefore, bending as well as axial loading occurred. Fig. 13 shows the stress distributions at the transition and at the test section of PU-10-Z for 0 kc, 2020 kc and 4294 kc. It will be noticed that the bending in the strong axis tended to increase slightly with life.

After comparing Figs. 12 and 13, it is seen that weak axis bending varies with the camber out of the plane of the specimen and that the actual maximum stress varies considerably from the nominal maximum stress, $P_{max.}/A$. Since the camber of the plain specimens vary from 1/64 inch to 1/32 inch, the actual stress and stress gradient at the point of initiation of the fatigue fracture will vary over a considerable range and will always exceed P/A. It was also observed that the actual stress concentration factor agreed quite well with the theoretical factor, 1.1.

2. WELDED TEE SPECIMENS

A. Comparison of Two Different Electrodes

At first sight, the S-N Curves of Fig. 11 would seem to indicate that there is no substantial difference in fatigue behavior between the "low strength" electrode and the "high strength" electrode. The sources of fracture initiation, however, listed in Tables 8 and 9 may indicate otherwise. In all cases where failure occurred in the test section of the "low strength" specimens, fractures were initiated at large gas pockets in the weld root, Fig. 14, within the limits of the 3/16 inch fillet tack weld. On the other hand, the fractures of the "high strength" specimens were initiated at several different types of defects, small gas pockets in the weld root, small blowholes in the weld face, arc strikes and weld spatters. It appears that the "high strength" welds were typical of those that one might generally find in practice since no one type of defect predominated in fracture initiation.

The welding process in the case of the "low strength" welds might have been defective. This is substantiated by several references[8, 9, 10] stating that small defects as isolated blowholes, porosity, inclusions, etc. do not appreciably reduce the fatigue strength of welds.

It is possible that if the gas pockets in the "low strength" welds had not been so large, failures might have been initiated at other defects as well and it is quite probable that the fatigue resistance of the "low strength" welds would have been superior to that of the "high strength" welds. Gas pockets can arise from flux trapped in the joint of the flange and web. They can also be caused by moisture absorbed in the flux. The latter reason is probably the more valid one in the present case.

B. Effect of Understressing

Two welded tee specimens were each tested at two different maximum stresses. W-11-H and W-12-H were considered as "run-outs" and were tested at higher maximum stresses. Fig. 11 shows that these specimens demonstrated a slight beneficial effect from understressing.

3. "PILOT" SMALL BEAM

The test result for the "pilot" small beam is indicated in Fig. 11. It agrees quite well with the S-N Curve for the "low strength" tee specimens. Since the pilot beam was fabricated from "as received" material and the tee specimens from descaled material, it appears that welding outweighs any detrimental effect due to descaling. It must be cautioned, in the light of data scatter typical of fatigue testing, that it is imprudent to draw far-reaching conclusions from one test point.

Fig. 15 is a photograph of the fracture surface of the pilot small beam indicating again the large gas pocket as the source of fracture initiation. In this case, insufficient shielding of the arc and presence of moisture in the flux probably caused the pocket. The insufficient shielding was due to the brittle flux falling away from the electrode and resulting in a bare electrode above the molten weld metal.

4. FITTING THE S-N CURVES

The reader will notice that the S-N Curves are plotted on semi-log paper, maximum stress arithmetic, fatigue life logarithmic, and he may wonder why the usual convention, a log-log plot, was not followed. The use of a log-log representation of fatigue data comes from Basquin[11] who, in 1910, presented the formula

$$S_{max.} = kN^{-m}$$

which will plot as a straight line on log-log paper. N is the fatigue life and k and m are constants determined by curve fitting procedures. There is no physical reason why fatigue data should follow this formula and, in the case of the present tests, it was found that the semi-log plot representing the formula

$$N = 10^{(S_{max.} - a)/b}$$

gave a superior fit to the data.

VI TESTS PROPOSED TO COMPLETE PRESENT PROGRAM

1. TEE SPECIMENS

In order to complete the axially loaded fillet welded sequence, it is proposed that 24 additional tee specimens be fabricated. Twelve will be tested at R = 0 and twelve at R = -1. An AWS-WRC Diagram will then be constructed in a manner similar to that used in the construction of Fig. 10. It is suggested that the "low-strength" electrode be used in these specimens since the "high strength" electrode did not prove to be superior.

2. SMALL BEAMS

To verify the similitude of the tee specimens with built-up beams, eighteen small beams should be fabricated. Six "type a" beams, Fig. 6, with 1-7/8 x 3/4 inch flanges and 6 x 3/8 inch web would be tested at R = 1/4 and six "type a" beams at R = 1/2. Stress ratios in which the minimum stress per cycle is compressive are avoided because of the local compressive stresses that would be introduced in the critical region due to the method of load application.

To study the effect of variation of flange width, it is proposed that six "type b" beams, Fig. 6, be tested at R = 1/2. The "type b" beams would be fabricated with 3 x 3/4 inch flanges and

5 x 3/8 inch webs. The "low strength" electrode would be used in the fabrication of these specimens also.

3. LARGE BEAMS

The present series would be terminated by the testing of four large built-up beams, Fig. 7, fabricated in the same manner as the tee specimens and the small beams. Two would be tested at R = 1/2 and two at R = 1/4. These tests would investigate the applicability of the tee specimen results to built-up beams of more practical proportions.

4. STUDY OF COMBINED STRESSES

Although the foregoing program studies the uniaxial stress condition exclusively, an additional series of six "type b" small beams could be tested at R = 1/2. Instead of a single 4-inch fillet tack weld being centered in the beam, tack welds would be located under each load point. The critical region of the flange-to-web fillet weld would then be in a state of combined alternating shear and tension. An equivalent uniaxial maximum stress could be computed from the distortion energy theory (or another suitable failure theory)[7] in the form

$$\sigma_e = \sqrt{\sigma^2 + 3\tau^2}$$

where σ_e = equivalent uniaxial maximum stress, σ = actual maximum tensile stress and τ = actual maximum shear stress. This equivalent uniaxial stress would be compared to the S-N Curve for R = 1/2 derived from the main test series.

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Professor L. S. Beedle is Director of Fritz Engineering Laboratory and Professor W. J. Eney is Head of the Civil Engineering Department and Fritz Engineering Laboratory.

VIII TABLES

TABLE 1 "T-1" STEEL USED IN TESTS

CHEMICAL COMPOSITION

C	0.16%	Ni	0.87%
Mn	0.83%	Cr	0.65%
P	0.017%	Mo	0.51%
S	0.019%	Cu	0.25%
Si	0.22%	B	0.003%

MECHANICAL PROPERTIES (3/4" P_L)

(Averages of 6 - 0.505" diameter polished tensile specimens)

Yield Strength 0.2% Offset	109.45 ksi
Ultimate Tensile Strength	120.38 ksi
Elongation in 2"	21.63%
Reduction of Area	64.27%
Modulus of Elasticity	29.52×10^3 ksi

HEAT TREATING CYCLE

Austenitizing Temp.		1700° F.
Time	3/4" P_L	70 min.
	3/8" P_L	43 min.
Tempering Temp.		1250° F.
Time	3/4" P_L	70 min.
	3/8" P_L	43 min.

TABLE 2 WELDING CONDITIONS

WELD	PROCESS	ELECTRODE	FLUX	CURRENT amps	VOLTAGE volts	TRAVEL SPEED ipm	PREHEAT TEMP. °F.	MAXIMUM INTERPASS TEMP. °F.
3/16 Tack	Manual shielded-metal-arc process	1/8" diameter E 11018 Atom Arc T	-	135	22	10	70	-
Final 1/4 Fillet "low strength"	Automatic submerged arc process	5/64" diameter Lincoln Electric No. L-70	Lincoln Electric No. 840	400	32	20	70	200
Final 1/4 Fillet "high strength"	Automatic submerged arc process	Page 8620	Linde Grade 80	300	33	15	70	200

TABLE 3 PLAIN SPECIMENS - DESCALED SURFACE R = 1/2

SPECIMEN	$S_{max.}$ ksi	LIFE kilocycles	DISTANCE "x" inches	LOCATION OF INITIATION OF FAILURE
P-1-H	77.0	2283.2	---	No failure
	110.0	165.3	1.50	Edge test section
P-2-H	100.0	3658.0	---	No failure
	110.0	460.7	3.0	Edge -transition
P-3-H	77.0	2966.4	---	No failure
	90.0	625.6	---	No failure
	100.0	539.0	3.25	Edge-transition
P-4-H	110.0	230.0	2.375	Edge-test section

$S_{min.} = 1/2\ S_{max.}$

TABLE 4 PLAIN SPECIMENS - DESCALED SURFACE
R = 0

SPECIMEN	$S_{max.}$ ksi.	LIFE kilocycles	DISTANCE "x" inches	LOCATION OF INITIATION OF FAILURE
P-1-Z	48	735.6	2.75	Unless noted: Failure was initiated at edge in test section
P-2-Z	94	62.5	0.25	
P-3-Z	94	81.8	0.50	
P-4-Z	44	792.2	1.00	
P-5-Z	76	90.2	1.375	
P-6-Z	76	145.8	3.00	Edge-transition
P-7-Z	76	105.0	1.00	
P-8-Z	40	3612.1	--	Grips
P-9-Z	56	470.9	1.00	
P-10-Z	56	384.4	2.50	
P-11-Z	56	462.2	0.187	
P-12-Z	94	36.1	2.75	

$S_{min.} = 0$

TABLE 5 PLAIN SPECIMENS - "AS RECEIVED" SURFACE
R = 0

SPECIMEN	$S_{max.}$ ksi	LIFE kilocycles	DISTANCE "x" inches	LOCATION OF INITIATION OF FAILURE
PU-1-Z	100	53.0	3.00	Unless noted: All failures were initiated at edge in transition
PU-2-Z	100	55.4	3.00	
PU-3-Z	99.5	64.2	3.00	
PU-4-Z	100	51.8	3.00	
PU-5-Z	90	86.8	3.00	
PU-6-Z	80	190.0	3.00	
PU-7-Z	60	600.5	3.00	
PU-8-Z	40	3967.4	---	No failure
	80	155.2	3.50	
PU-9-Z	58	2438.0	0.625	Failed in grips at 1740 kc Failed in test section at 2438 kc
PU-10-Z	50	4294.0	---	No failure
	80	137.6	2.00	Edge-test section
PU-11-Z	58	567.3	1.75	Edge-test section
PU-12-Z	58	411.1	3.00	

$S_{min.} = 0$

PLAIN SPECIMENS - "AS RECEIVED" SURFACE

TABLE 6 R = -1

SPECIMEN	$S_{max.}$ ksi	LIFE kilocycles	DISTANCE "x" inches	LOCATION OF INITIATION OF FAILURE
				Unless noted:
PU-1-R	60	86.6	3.00	Failures initiated at edge in transition
Pu-2-R	40	436.4	3.00	
PU-3-R	50	89.0	3.00	
PU-4-R	30	3055.1	--	No failure
	43	319.5	3.25	
PU-5-R	45	133.6	0.50	Edge-test section
PU-6-R	55	100.9	2.00	Edge-test section
PU-7-R	45	126.5	0.25 3.00	Edge-test section Edge-transition
PU-8-R	38	338.1	3.50	
PU-9-R	40	209.6	3.375	
PU-10-R	48	142.8	3.25 3.75	
PU-11-R	35	629.3	3.75	
PU-12-R	32	4121.4	--	No failure
	50	127.5	3.50	

$S_{min.} = -S_{max.}$

TABLE 7 PLAIN SPECIMENS - "AS RECEIVED" SURFACE R = 1/4

SPECIMEN	$S_{max.}$ ksi	LIFE kilocycles	DISTANCE "x" inches	LOCATION OF INITIATION OF FAILURE
PU-1-Q	100	52.3	3.25	Edge-transition
PU-2-Q	60	403.8	2.625	Edge-test section
PU-3-Q	61.1	4244.8	--	No failure
	80	220.4	3.00	Center-wide face
PU-4-Q	70	815.2	3.50	Center-wide face
PU-5-Q	76	179.5	1.00	Edge-test section
PU-6-Q	84	168.1	2.25	Edge-test section
PU-7-Q	88	101.3	0.25	Edge-test section
PU-8-Q	64	375.6	3.25	Edge-transition
PU-9-Q	76	176.5	2.00	Edge-test section
PU-10-Q	68	472.4	2.25	Edge-test section
PU-11-Q	63	624.2	1.375	Edge-test section
PU-12-Q	62	420.4	1.75	Edge-test section

$S_{min.} = 1/4\ S_{max.}$

TABLE 8 WELDED TEE SPECIMENS - R = 1/2

LINCOLN L-70 ELECTRODES (low strength)

SPECIMEN	$S_{max.}$ ksi	LIFE kilocycles	DISTANCE "x" inches	LOCATION OF INITIATION OF FAILURE
				Unless Noted: Failures were initiated at gas pockets in weld roots
W-1-H	60	925.7	1.75	
W-2-H	86	269.0	1.25	
W-3-H	102	126.5	1.00	
W-4-H	60	1157.9	--	Grips
W-5-H	74	513.0	2.375	
W-6-H	74	658.8	2.25	had surface gas pocket - not at flu pt
W-7-H	60	891.9	0.25	Ditto
W-8-H	50	1970.8	0.75	
W-9-H	50	1372.5	0.25	
W-10-H	86	297.0	2.00	
W-11-H	48	3806.0	--	No Failure
	70	784.3	--	Grips
W-12-H	46	4491.0	--	No Failure
	86	554.1	0.00	

$S_{min.} = 1/2\ S_{max.}$

TABLE 9 WELDED TEE SPECIMENS - R = 1/2

PAGE 8620 ELECTRODES (high strength)

SPECIMEN	$S_{max.}$ ksi	LIFE kilocycles	DISTANCE "x" inches	LOCATION OF INITIATION OF FAILURE
W-20-H	70	523.0	2.75	Small blow hole - weld face
W-21-H	80	820.1	3.00	? - web surface ??
W-22-H	58	904.0	3.00	Small blow hole - weld face
W-23-H	56	3421.7	--	Grips
W-24-H	66	761.7	2.375	Small gas pocket - weld root
W-25-H	90	250.0	3.00	? - flange surface ?
W-26-H	60	1497.3	2.00	Arc strike - flange
W-27-H	86	387.1	0.75 1.50	Gas pocket - weld root Weld spatter - flange edge
W-28-H	70	414.3	2.25	Arc strike - web
W-29-H	60	1140.3	2.50	Gas pocket - weld root
W-30-H	66	620.5	2.00	Gas pocket - weld root
W-31-H	90	328.1	0.00	Gas pocket - weld root

$S_{min.} = 1/2\ S_{max.}$

TABLE 10 COMPARISON OF SURFACE HARDNESSES DESCALED AND "AS RECEIVED" PLAIN SPECIMENS

SPECIMEN	ROCKWELL C HARDNESS MACHINED EDGE	ROCKWELL C HARDNESS FACE
PU-3-R ("as received")	28	21
		15
		27
		21
		22
		23
		21
		26
	Average =	22
P-8-Z (descaled)	29	34
		27
		21
		22
		27
		22
		24
		22
	Average =	25

IX FIGURES

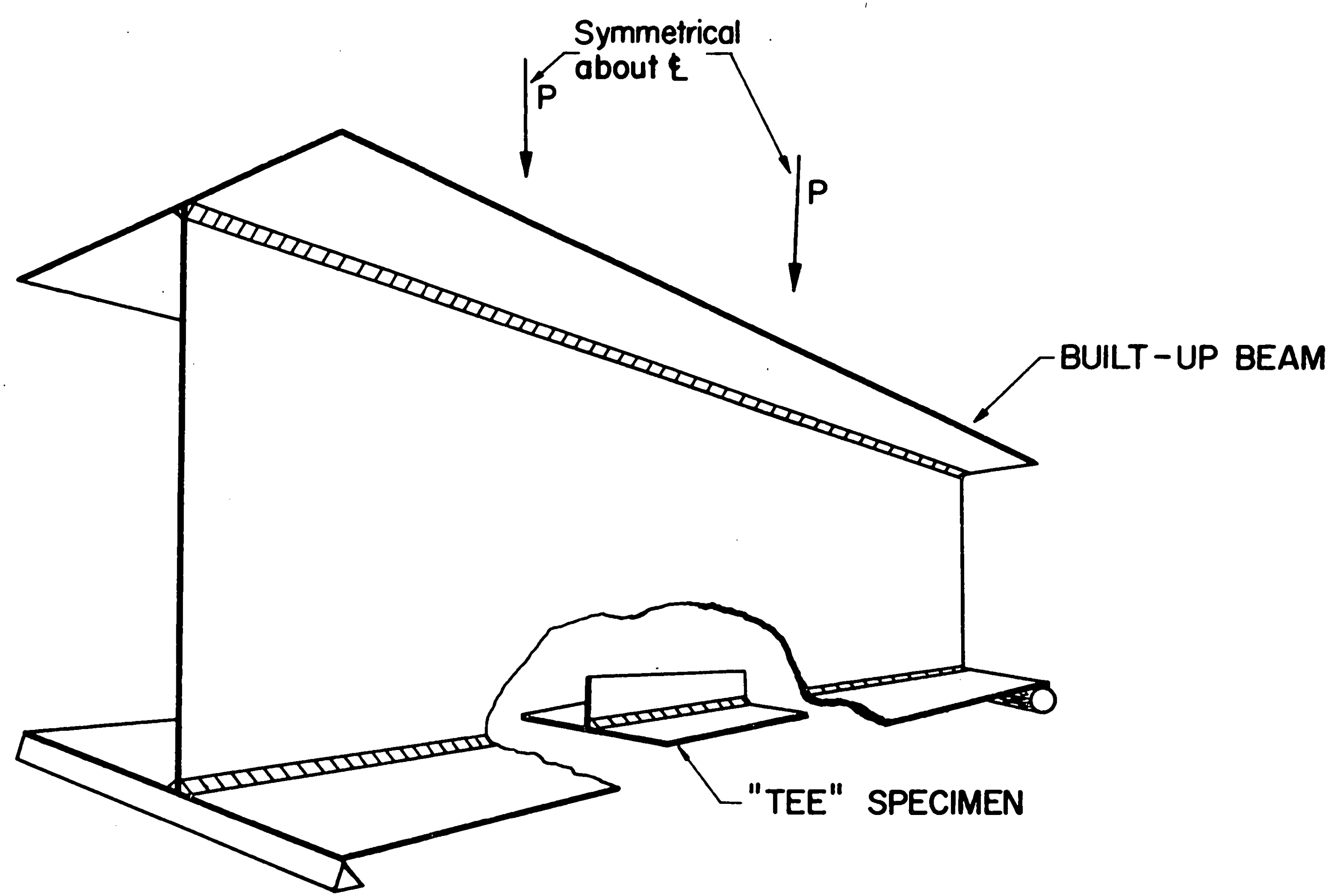


FIG. 1 SIMULATION OF CRITICAL ZONE OF WELDED BUILT-UP BEAM BY AXIALLY LOADED "TEE" SPECIMEN

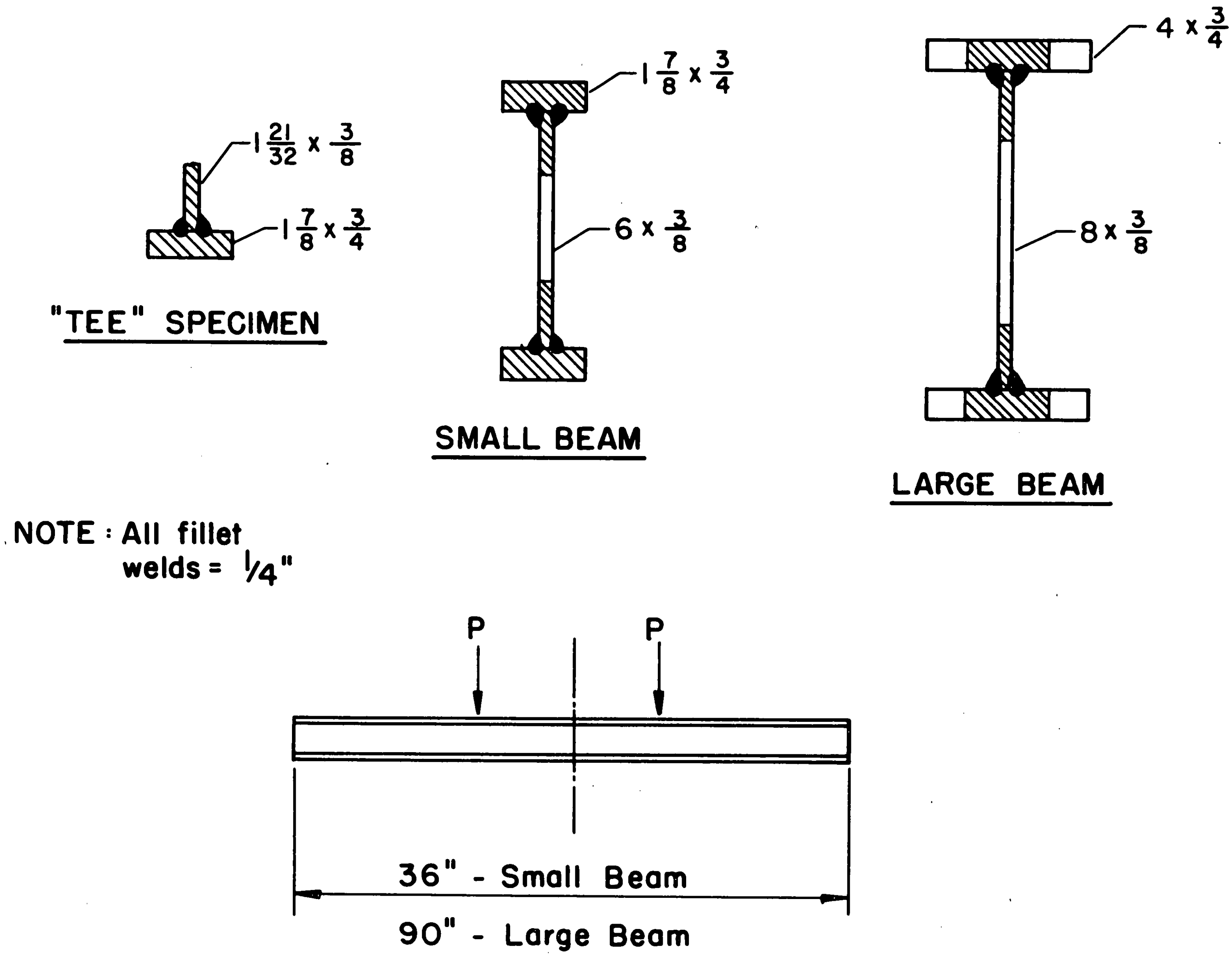


FIG. 2 GEOMETRIC SIMILARITY OF SPECIMENS

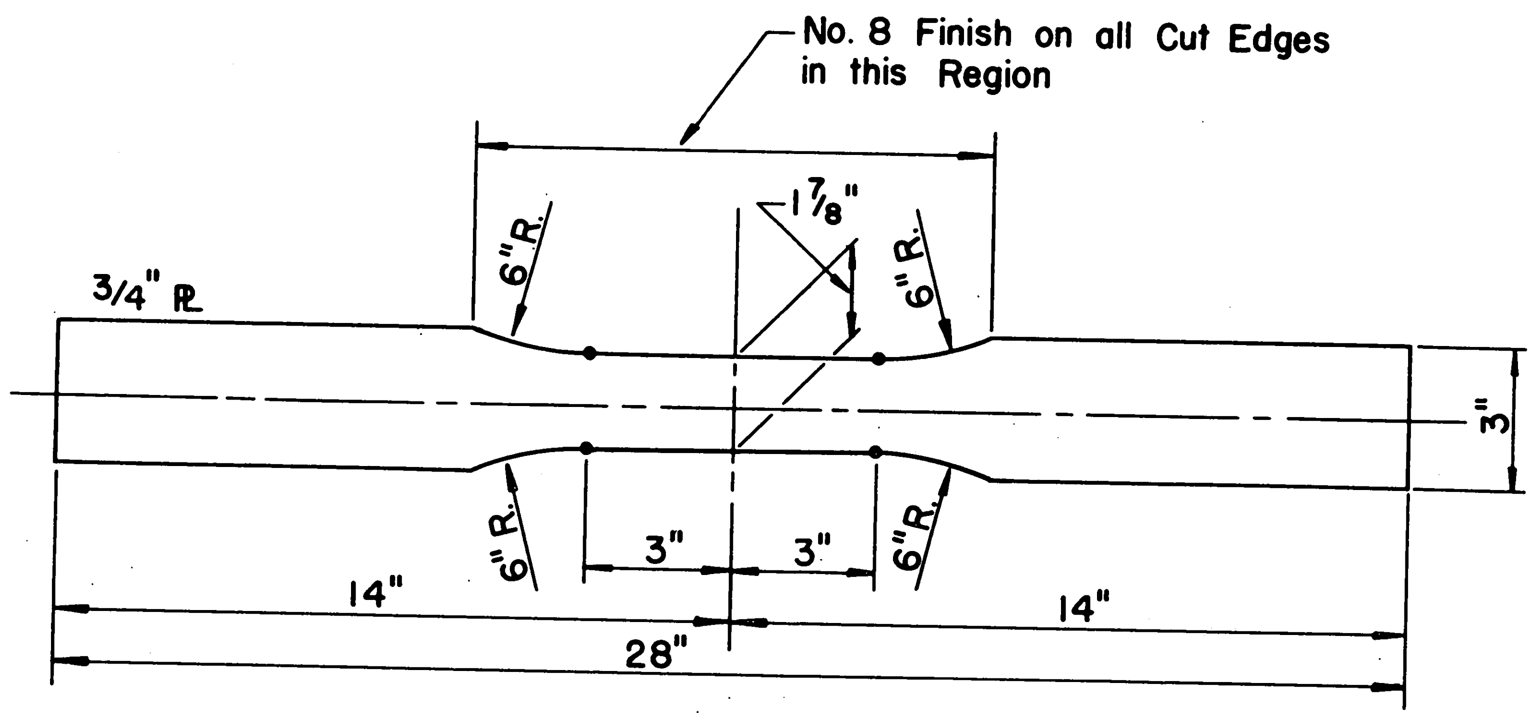


FIG. 3 PLAIN SPECIMEN

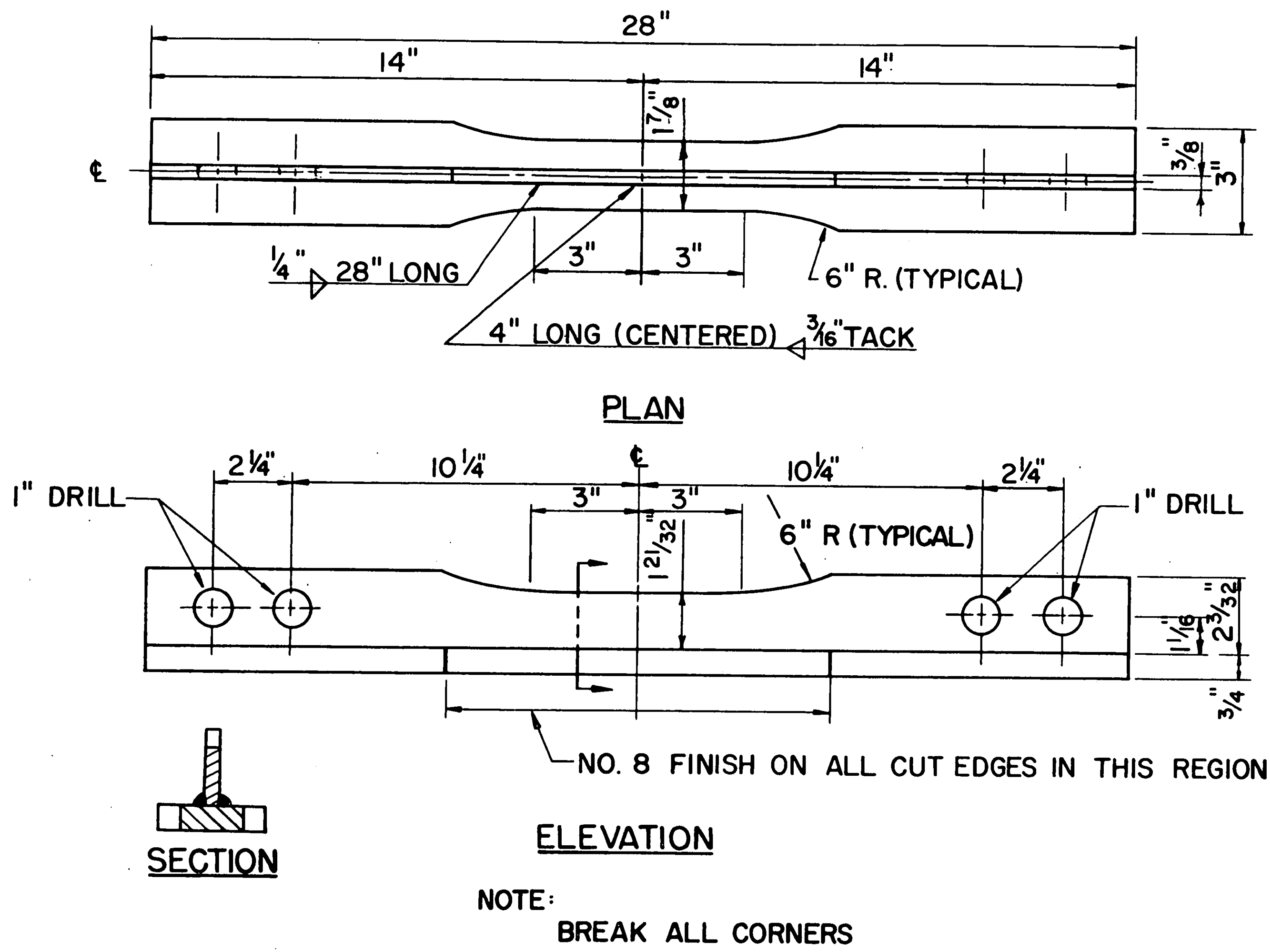


FIG. 4 LONGITUDINAL FILLET-WELDED "TEE" SPECIMEN

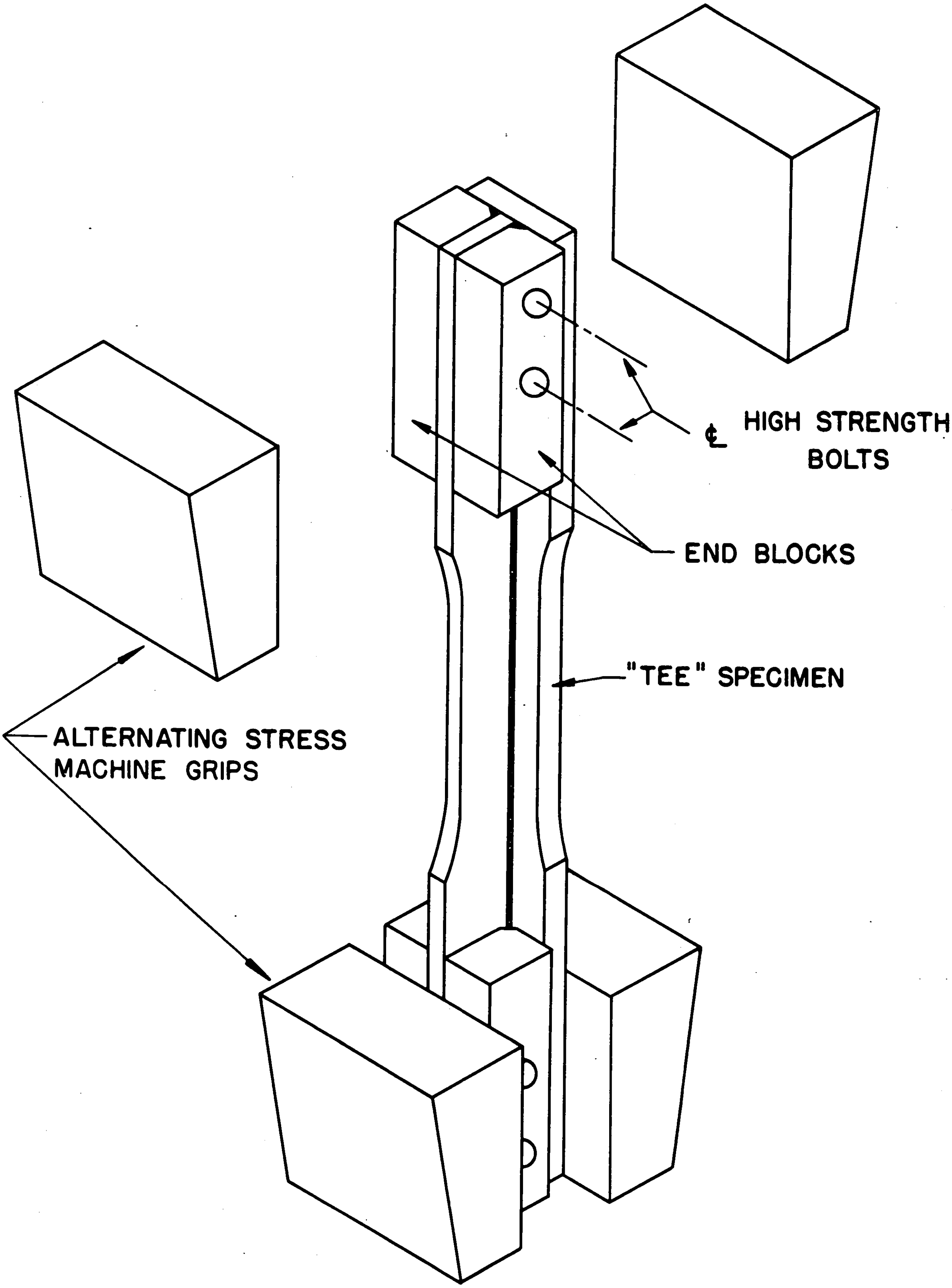


FIG. 5 TEST SET-UP "TEE" SPECIMEN

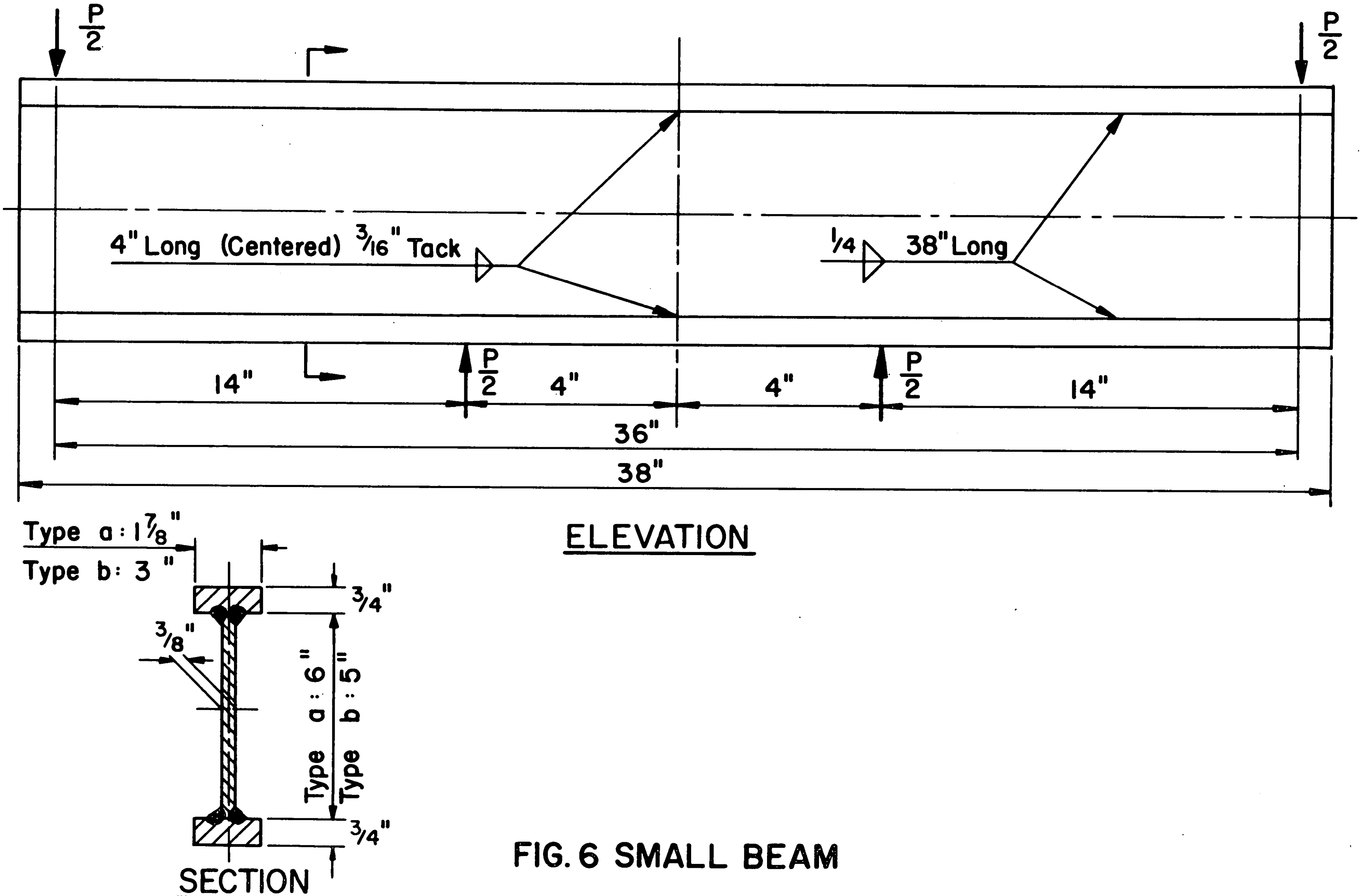


FIG. 6 SMALL BEAM

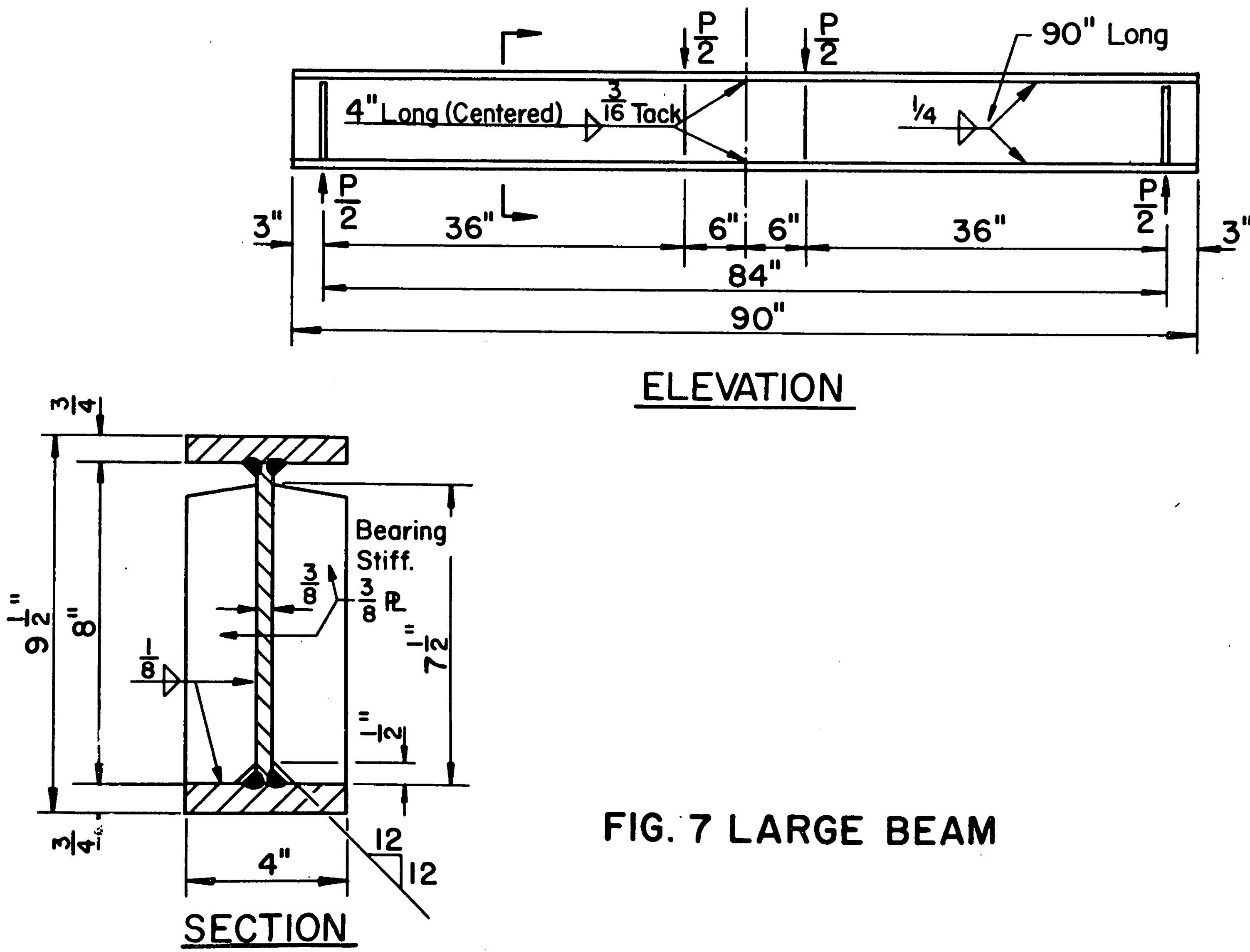


FIG. 7 LARGE BEAM

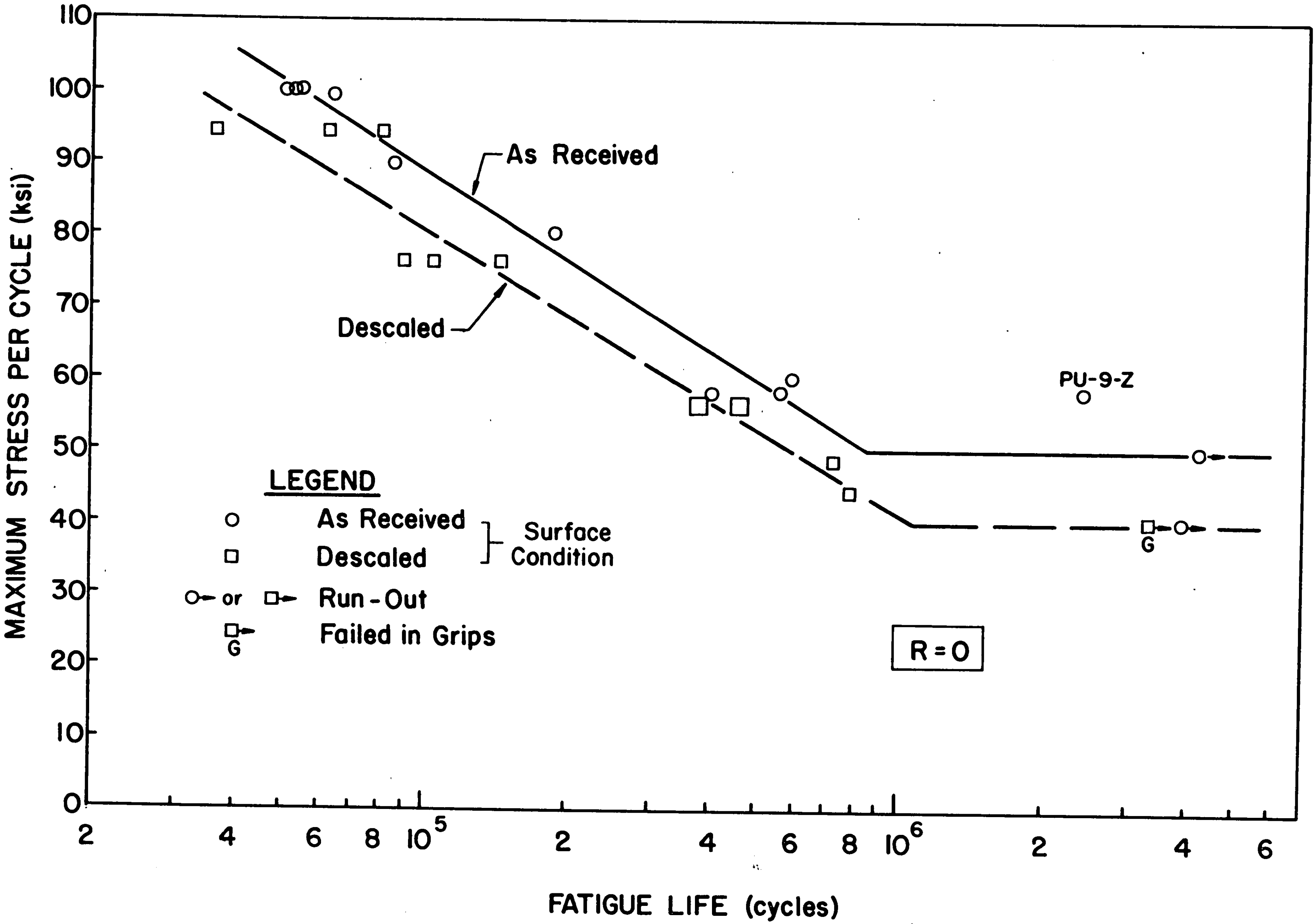


FIG. 8 S-N CURVES-COMPARISON OF DESCALED AND "AS RECEIVED" PLAIN SPECIMENS

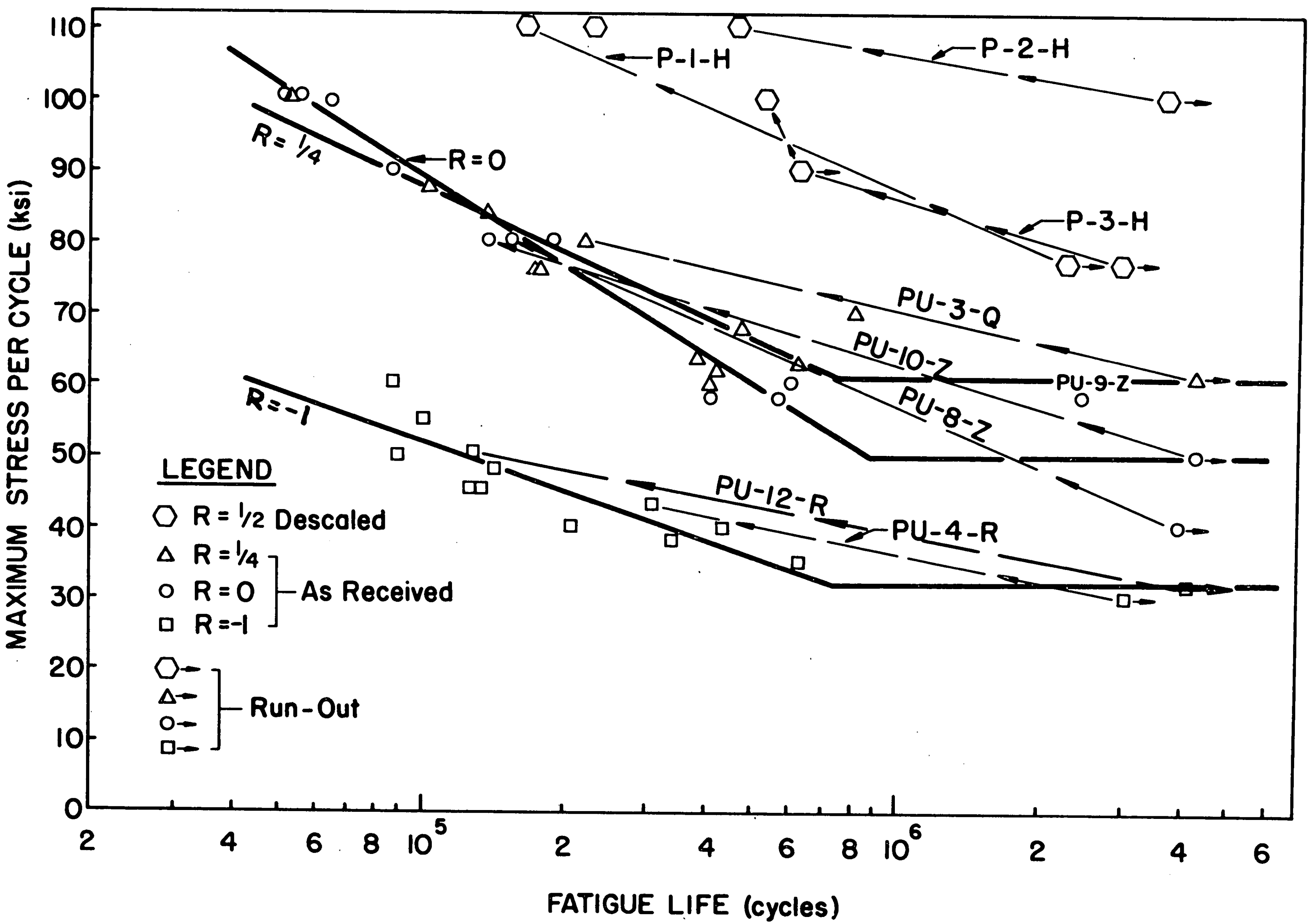


FIG. 9 S-N CURVES-PLAIN SPECIMENS "AS RECEIVED" SURFACE

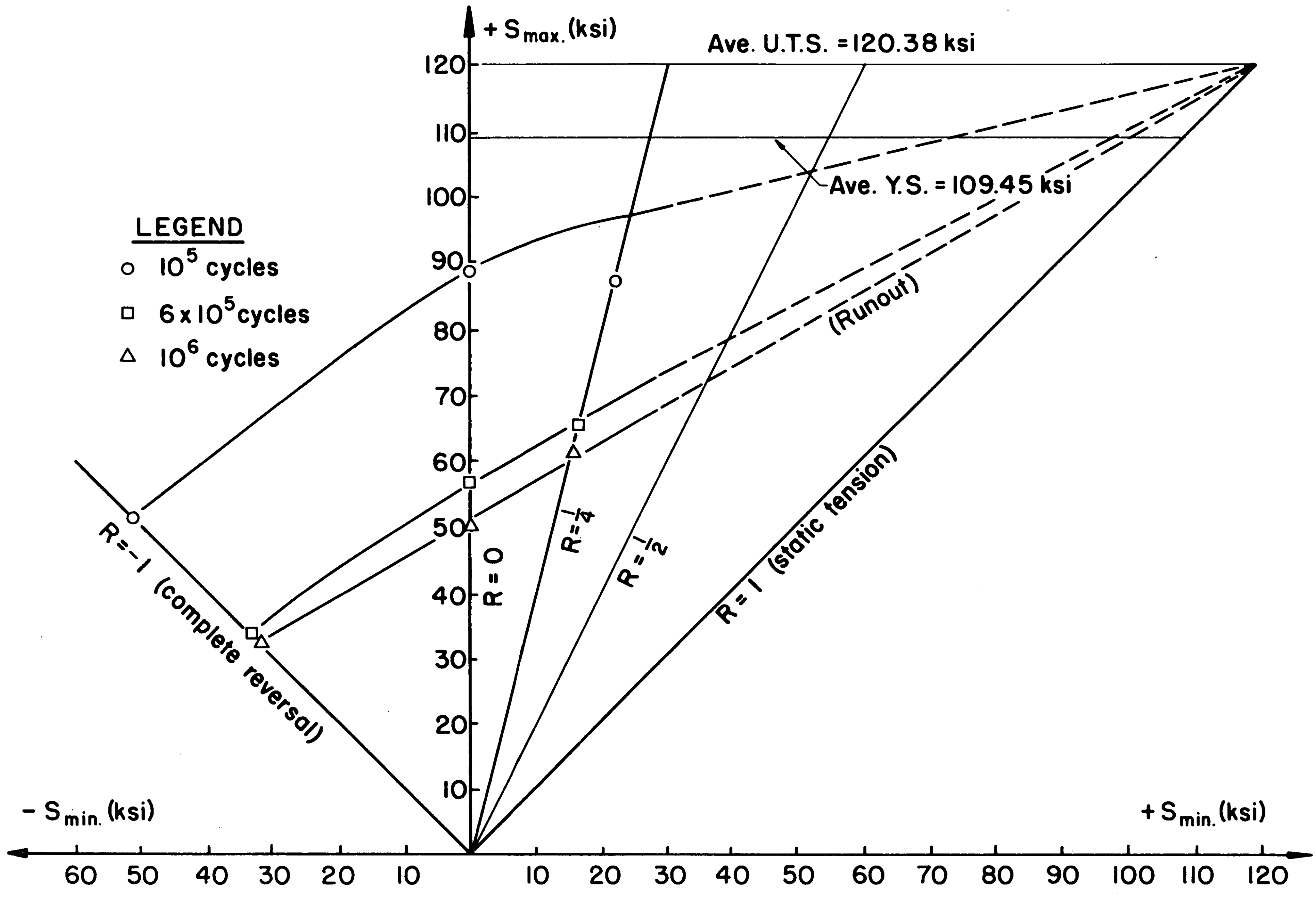


FIG. 10 AWS-WRC DIAGRAM - PLAIN SPECIMENS "AS RECEIVED" SURFACE

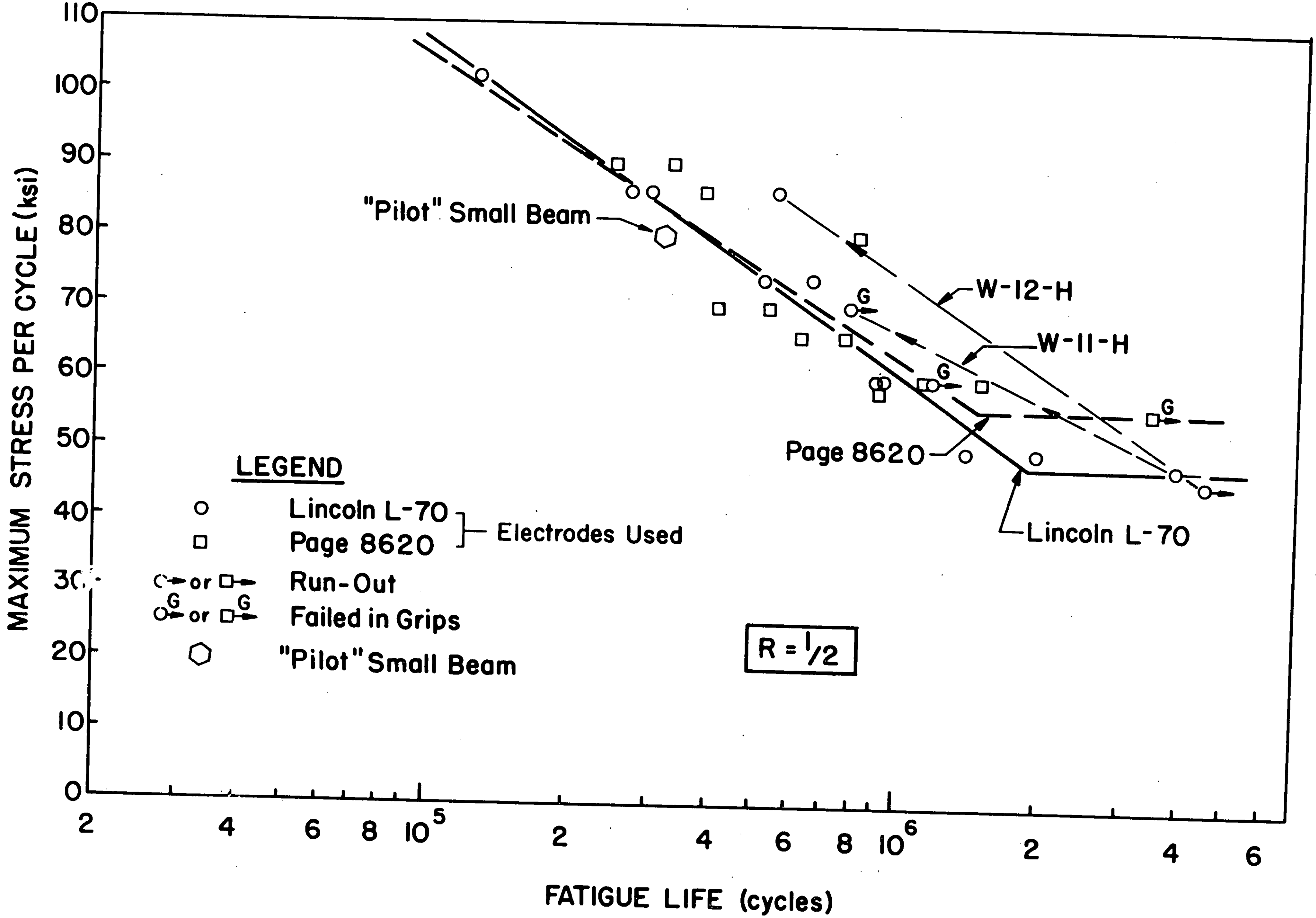
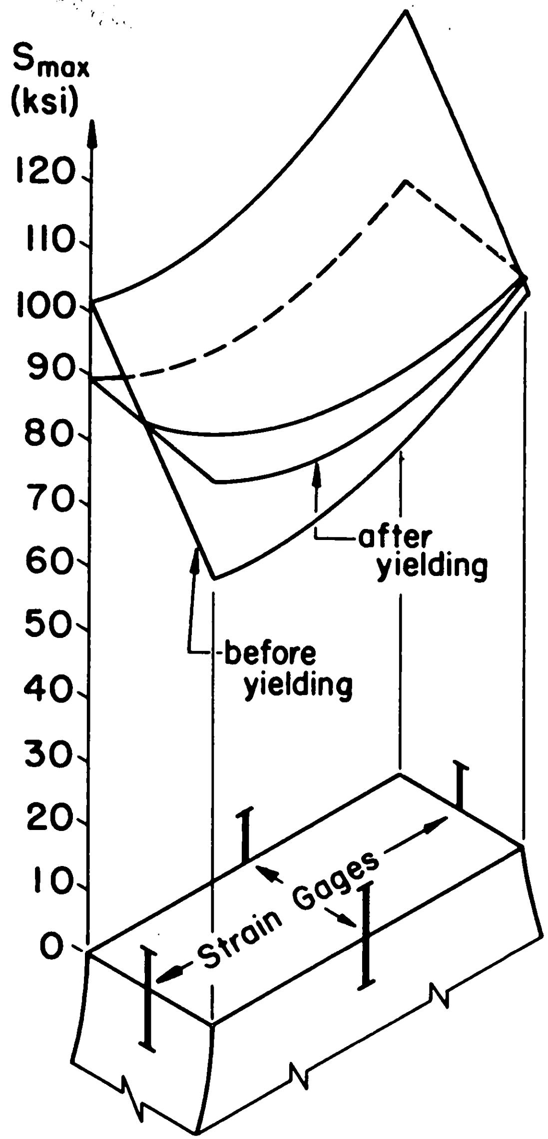
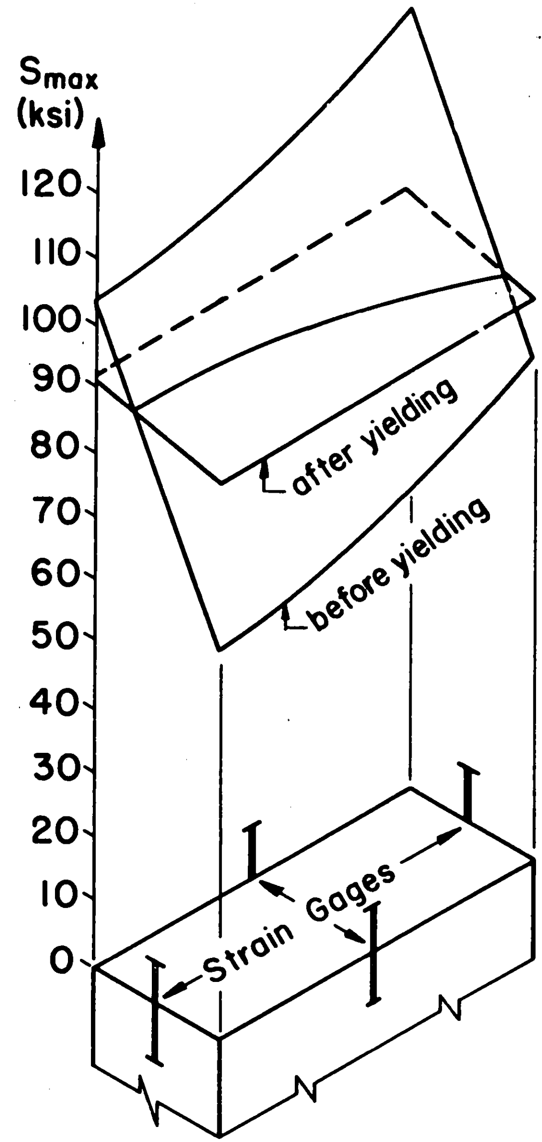


FIG. 11 S-N CURVES-COMPARISON OF TWO DIFFERENT ELECTRODES-WELDED "TEE" SPECIMENS



a. STRESS DISTRIBUTION - TRANSITION

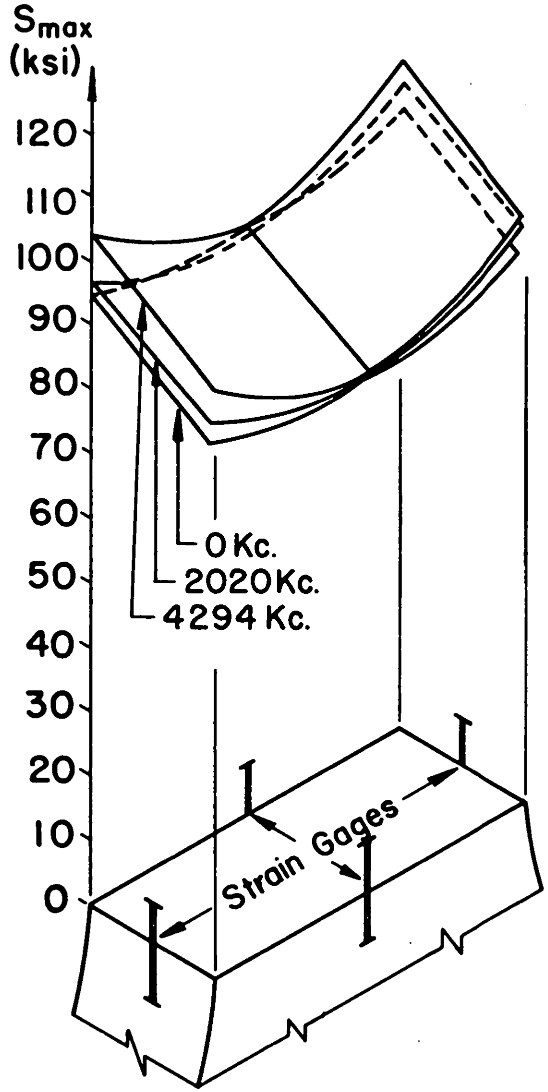
$\frac{P}{A} = 89$ ksi



b. STRESS DISTRIBUTION - TEST SECTION

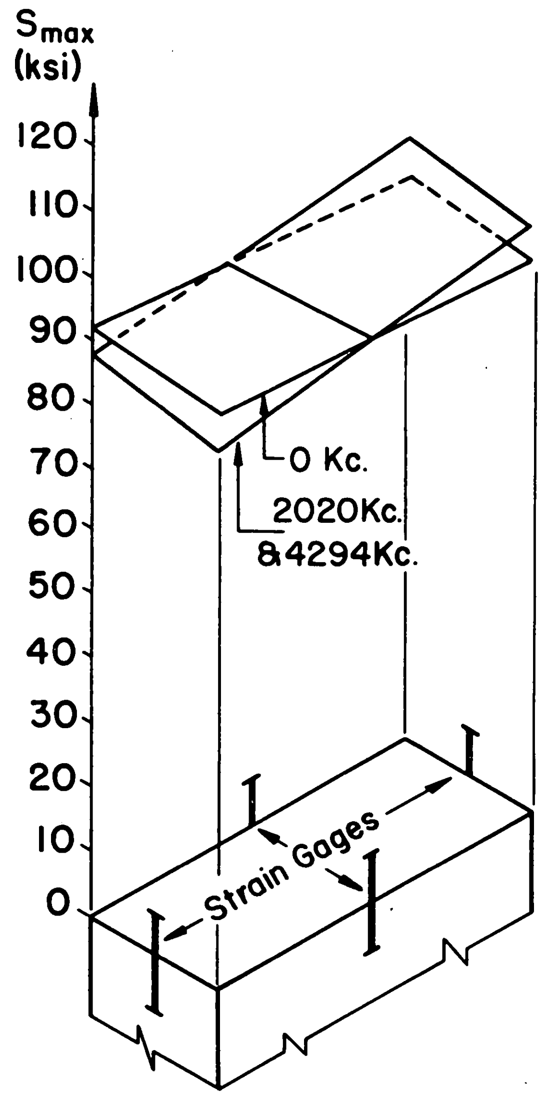
$\frac{P}{A} = 89$ ksi

FIG. 12 STRESS DISTRIBUTION - SPECIMEN P-I-H



a. STRESS DISTRIBUTION - TRANSITION

$\frac{P}{A} = 89.4$ ksi



b. STRESS DISTRIBUTION - TEST SECTION

$\frac{P}{A} = 89.4$ ksi

FIG. 13 STRESS DISTRIBUTION - SPECIMEN PU-10-Z

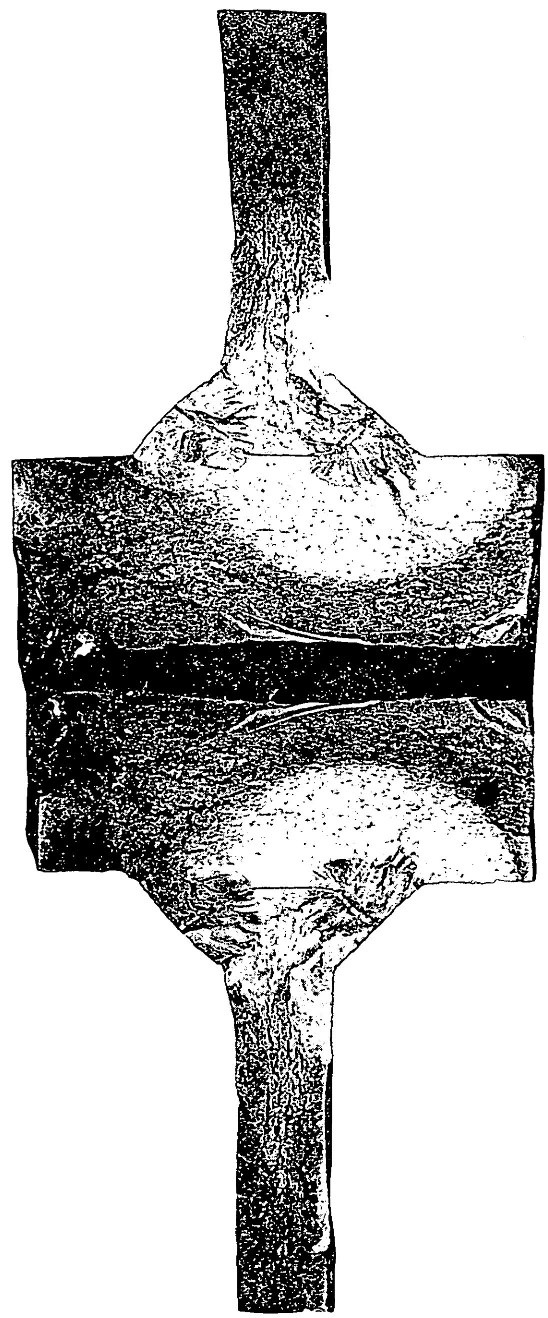


FIG. 14 FRACTURE SURFACE-"TEE" SPECIMEN

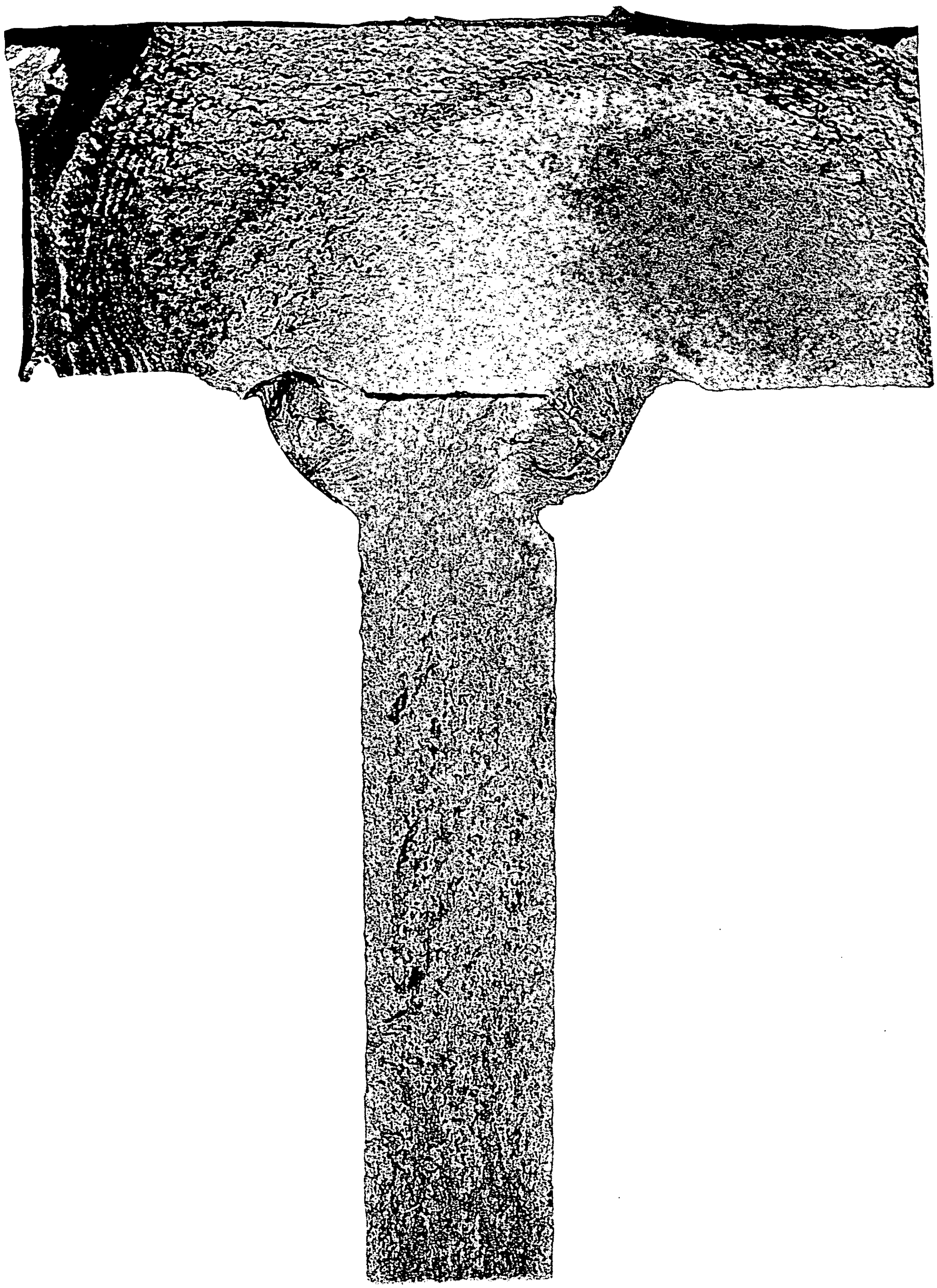


FIG. 15 FRACTURE SURFACE-"PILOT" SMALL BEAM

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